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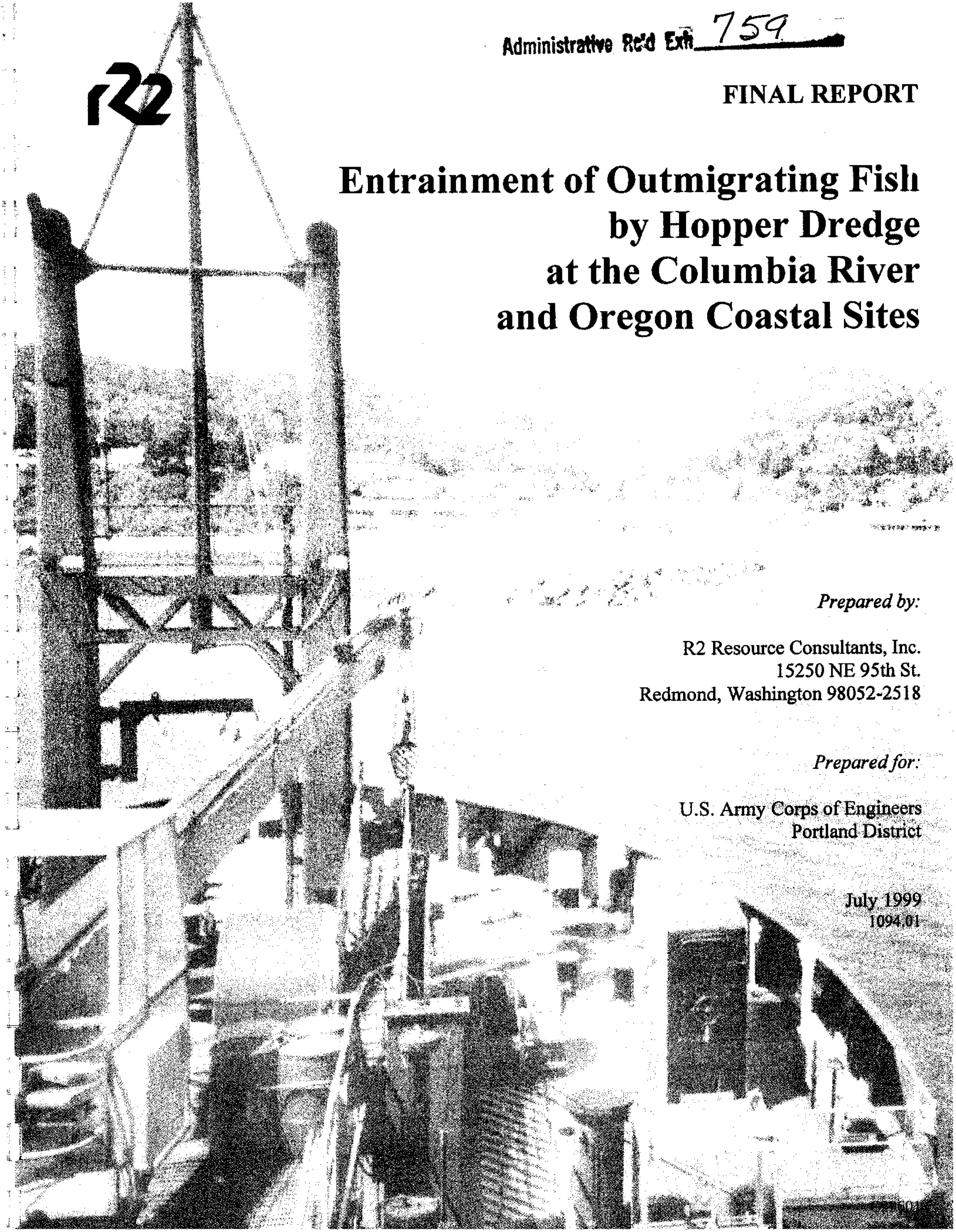

FINAL REPORT

Entrainment of Outmigrating Fish by Hopper Dredge at the Columbia River and Oregon Coastal Sites

Prepared by:

R2 Resource Consultants, Inc.
15250 NE 95th St.
Redmond, Washington 98052-2518

Prepared for:

U.S. Army Corps of Engineers
Portland District

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1. INTRODUCTION

Many navigable waterways of the United States require maintenance dredging to allow for the passage of commercial and recreational vessels. Dredging is a practice whereby the bottom substrate of a channel or harbor is dredged and moved to another location, typically resulting in a deeper waterway. The dredge spoils can be deposited at disposal sites located on land, and/or in open water within a river or the ocean. Dredging is required annually at many locations because sediments are constantly moving downstream in riverine systems. In addition, sand bars may develop near estuaries as a result of longshore sediment transport along the coast. These processes require a program of periodic dredging in order to maintain navigable waterways.

The Portland District Army Corps of Engineers (USACE) operates two hopper dredges, the *Yaquina* and the *Essayons* that dredge and transport spoils to open water disposal sites. Organisms that dwell in benthic substrates as well as organisms present in the open water including anadromous salmonids (*Oncorhynchus* spp.) may be entrained during dredging.

Research on entrainment of anadromous salmonids by hopper dredging is limited, with most research focused on impacts to the water column, areas adjacent to dredging, and disposal operations. The first studies in the Northwest on entrainment impacts to salmonids were conducted in the Fraser River, Canada (Dutta and Sookachoff 1975). The few hopper dredge tests that were conducted during that study led researchers to conclude that anadromous fish were entrained and that they did not survive in the hopper. This led to restrictions that limited dredging operations to times outside of the peak juvenile salmon outmigration period. However, subsequent studies (Arseneault 1982) reported lower estimates of salmonid entrainment, leading to a lessening of dredging restrictions.

Four entrainment studies have been conducted in Grays Harbor, Washington (Bengston and Brown 1977; Tegelberg and Authur 1977; Stevens 1981; and Armstrong et al. 1982). Of these, the study by Armstrong et al. (1982) was the only one that calculated fish entrainment per cubic yard of dredge material, and was also the only study in which anadromous salmonids were collected. Entrainment of all fish was generally less than 0.1 fish per cubic yard, and was 0.008 per cubic yard for the one chum salmon that was collected.

From 1985 to 1988, the Portland District USACE conducted studies to determine the number of Dungeness crabs and other organisms entrained by hopper dredging at the mouth of the Columbia River (Larson 1993). During those studies, 789 entrainment samples were collected yielding 14 taxa of fish. No salmonids were collected, with eulachon *(Thaleichthys pacificus)* the only anadromous species entrained.

In 1997, in response to concerns expressed by the National Marine Fisheries Service (NMFS) the Portland District USACE began collecting more data to assess potential entrainment of anadromous salmonids during normal maintenance dredging operations. NMFS was concerned that several salmonid species listed or proposed for listing under the Federal Endangered Species Act (ESA) may be potentially affected by the dredging. Sampling was conducted for salmonid entrainment on the lower Columbia River and at several ports along the Oregon Coast during 1997 and 1998. As a result, sampling was conducted on two occasions at two sites located in the lower Columbia River, and on one occasion at five sites located along the Oregon Coast (Figure 1). The Oregon Coast sites were located generally at the mouths of five river systems in a north to south direction: the Yaquina, Siuslaw, Umpqua, Rogue, and Chetco rivers. For purposes of this report, we define these seven sites as the Project Area. The overall objective of this study was to determine if migrating juvenile salmon were being entrained during normal maintenance dredging operations. This report summarizes the results of the 1997 and 1998 entrainment studies.

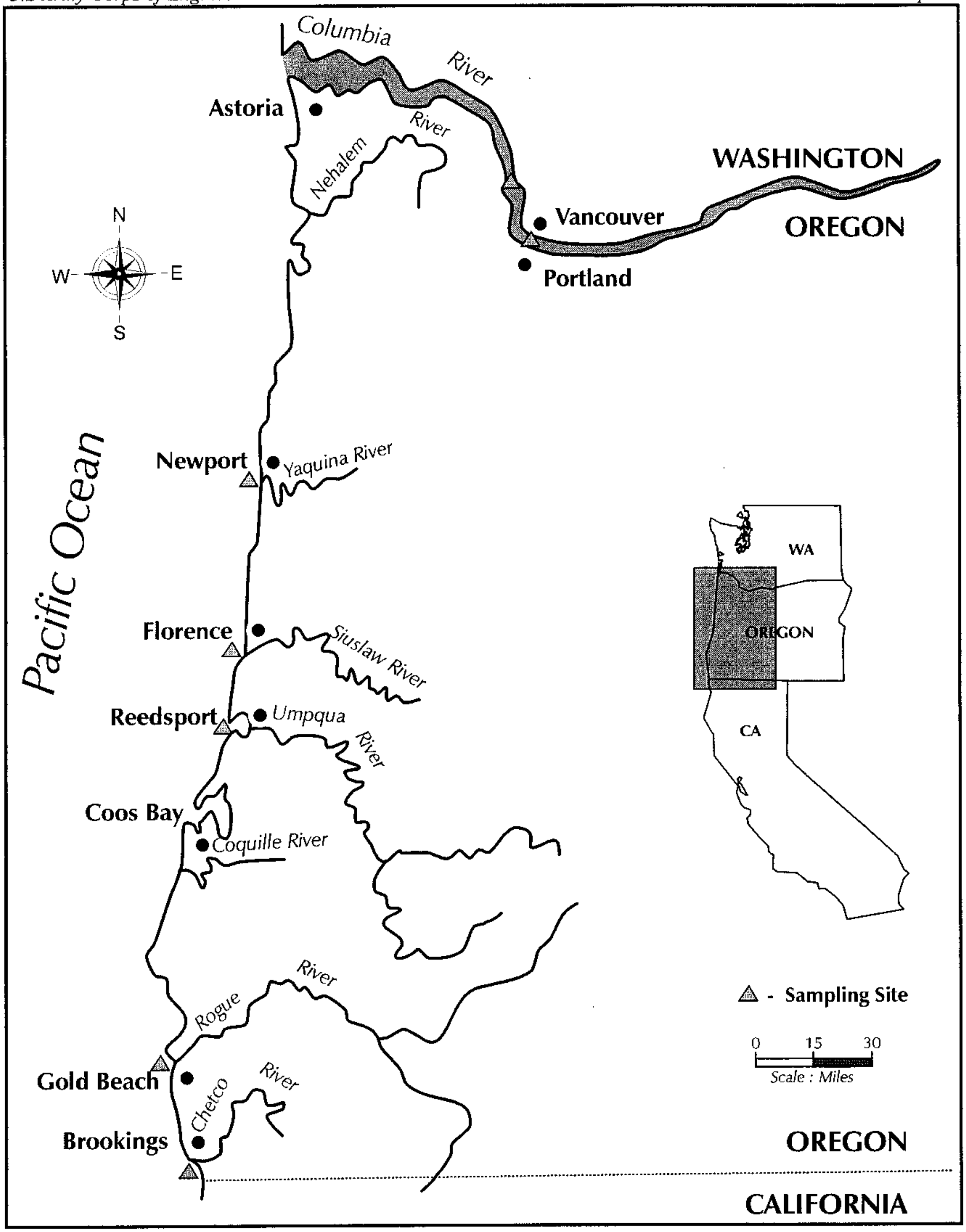


Figure 1. Site map of dredge sampling locations on the lower Columbia River and the Oregon Coast, 1997 and 1998.

C29608

2. BACKGROUND AND STUDY CONTEXT

2.1 SALMONID LIFE STAGE VULNERABILITY TO DREDGING

This dredging study was focused on determining whether salmonid fishes that may be present within areas undergoing dredging activities are vulnerable to entrainment and subsequent mortality. Although special consideration was given to those species listed under the ESA, information was also sought for non-listed species that may be present within waters of the Project Area. This section discusses both the status and distribution of ESA listed species, as well as the timing of downstream migrations of both listed and non-listed species through Project Area waters.

Anadromous salmon and steelhead adults spend one to several years in the ocean where they grow and mature before returning to their natal stream to spawn. The eggs are deposited into clean gravel, referred to as a nest or a redd. Adult salmon die after spawning, while steelhead trout can return to the ocean as kelts and are capable of repeat spawning. In Washington and Oregon streams, the eggs remain buried in the gravel for 1 to 4 months, depending on species and environmental conditions. After emerging from the gravel, the fry/juvenile salmon and trout can remain in the natal stream for days, months, or several years depending on the species, race, and stock of fish before migrating downstream (as smolts or sub-yearling) to the ocean. It is during this downstream migration period that juvenile salmon and trout would be most susceptible to dredging activities.

2.2 CURRENT ESA STATUS OF PACIFIC COAST SALMONIDS

Salmonid species currently listed (as of May 21, 1999) or proposed for listing under the ESA and that may at times be present in the Project Area are summarized in Table 1, by species. These listings span a range of about 7.5 years from the earliest listing of Snake River sockeye salmon as "endangered" in 1991, to the most recent listings of Lower Columbia chinook salmon (threatened), Upper Columbia Spring chinook salmon (endangered), Columbia River chum salmon (threatened), Middle Columbia steelhead (threatened), and Upper Willamette steelhead (threatened) in March 1999.

C29609

Table 1. Current Federal Endangered Species Act (ESA) status of Pacific anadromous salmonids that may be present within waters or downstream areas periodically dredged by the U.S. Army Corps of Engineers (USACE).

Species	Evolutionarily Significant Unit (ESU) [1]	Status	Date of Listing
Chinook Salmon (*Oncorhynchus tshawytscha*)	Lower Columbia River ESU	T	3/99
	Mid-Columbia River Spring-run ESU	NW	3/98
	Upper-Columbia River Spring-run ESU	E	3/99
	Upper-Columbia River Summer/Fall-run ESU	NW	3/98
	Snake River Fall-run ESU	T	4/92
	Snake River Spring/Summer-run ESU	T	4/92
	Upper Willamette River ESU	T	3/98
	Oregon Coast ESU	NW	3/98
	Southern Oregon and California Coastal ESU	T*	3/98
Coho Salmon (*Oncorhynchus kisutch*)	Southwest Washington/Lower Columbia River ESU	C	7/95
	Oregon Coast ESU	T	8/98
	Southern Oregon and Northern California Coast ESU	T	5/97
Sockeye Salmon (*Oncorhynchus nerka*)	Snake River ESU	E	11/91
Chum Salmon (*Oncorhynchus keta*)	Columbia River ESU	T	3/99
	Pacific Coast ESU	NW	3/98
Pink Salmon (*Oncorhynchus gorbuscha*)	Even-year ESU	NW	10/95
	Odd-year ESU	NW	10/95
Steelhead (*Oncorhynchus mykiss*)	Lower Columbia River ESU	T	3/98
	Middle Columbia River ESU	T	3/99
	Upper Columbia River ESU	E	8/97
	Snake River Basin ESU	T	8/97
	Upper Willamette River ESU	T	3/99
	Oregon Coast ESU	C	3/98
	Northern California ESU	C	3/98
Sea-run Cutthroat Trout (*Oncorhynchus clarki*)	Umpqua River ESU	E DL	8/96 3/99
	Columbia River/Southwestern Washington ESU	T*	3/99
	Oregon Coast ESU	C	4/99
	All other Oregon coast population	NW	4/99

E-Endangered, T-Threatened, * - Proposed as "E" or "T", NW- Listing not warranted, DL - Proposed de-listing
[1] - A distinct population of Pacific salmon or trout, and hence a species under the Endangered Species Act.

C29610

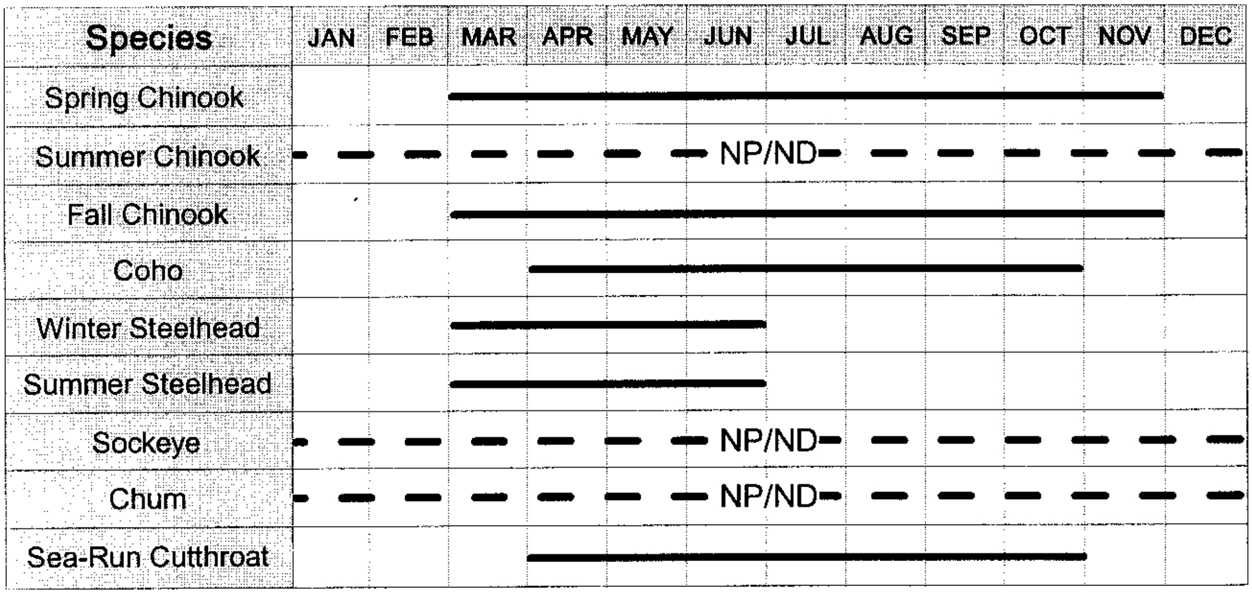
2.3 DISTRIBUTION OF SALMONID SPECIES IN PROJECT AREA WATERS

ESA listed species of anadromous salmon and trout found in Project Area rivers and estuaries are presented in Table 2. Anadromous salmon and trout use the study sites within the lower Columbia River as a migratory route. The Oregon Coast study sites contain estuary and coastal habitat which may be used as anadromous salmonid migratory routes, and/or as juvenile rearing habitat. The timing of downstream migrations and estuary residence for each site are presented in Figures 2 through 4.

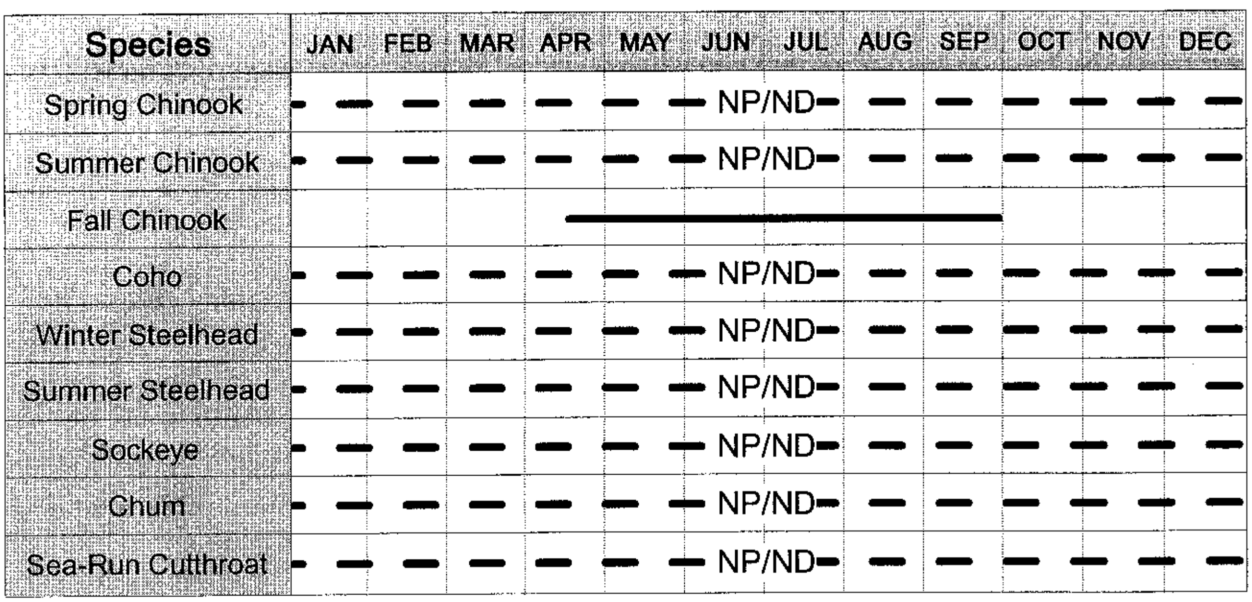
Table 2. Listed anadromous salmon and trout potentially present in Project Area waters.

Location	Species
Columbia River	chinook salmon, coho salmon, sockeye salmon, chum salmon, and steelhead
Yaquina River	coho salmon, and steelhead
Siuslaw River	coho salmon, and steelhead
Umpqua River	coho salmon, steelhead, and sea-run cutthroat
Rogue River	coho salmon, and steelhead
Chetco River	coho salmon, and steelhead

ROGUE RIVER



CHETCO RIVER



NP/ND - not present or no data available.

Figure 4. Periodicity tables depicting the timing of downstream migrations and estuary residence for salmonids that may be present in the Rogue and Chetco river (Monaco et al. 1990; Oregon Water Resources Research Institute 1995; and personal communications with ODFW staff 1998.)

C29612

3. SAMPLING

3.1 VESSEL AND SAMPLING EQUIPMENT

3.1.1 Vessel

The sampling completed during this study was conducted on USACE dredge vessel *Yaquina*. The *Yaquina* is a 200-foot hopper dredge that supports two dragarms, one on each side of the vessel. The dragarms are attached to dragheads, which are lowered to the river or estuary bottom. Pumps draw water and substrate material through the dragheads and dragarms and into the hopper. The hopper is a large compartment in the middle of the vessel used to store the dredged material. Once the hopper is full, the vessel moves to a disposal site, where the hopper is emptied through a set of large doors located on the bottom of the vessel. For purposes of this study, the vessel *Yaquina* was especially equipped with a device to separate organisms and debris from the fine sediments and sand which comprised most of the dredge material.

3.1.2 Sampling Equipment

The entrainment sampler was developed by the Plant Branch of the Portland District USACE. It was designed to sample dredged material before it is deposited into the hopper. The sampling equipment is comprised of two parts. The first part consists of approximately 5 by 3½ feet of metal grating comprised of ¼-inch by 1¼-inch steel bars set on edge and spaced ¼ inch apart. The grating is fitted into the top of the hopper, between the slurry outfall and the hopper bin. As the slurry passes over the steel grating, most of the sediments and water pass though the ¼-inch slots and into the hopper. The remainder of the slurry, mostly containing the larger materials and organisms, is deposited into the second piece of sampling equipment, a large collection basket. The basket is composed of ¼-inch steel mesh (Figure 5). During sampling, the basket sits in a steel frame and is located below the grated outfall. The steel frame was designed to hold the basket securely in place with less than a ½-inch clearance between the collection basket and the grating. The collection basket is removed from the hopper and raised to deck level using a hydraulic winch. Once the basket is on deck the sample is sorted.

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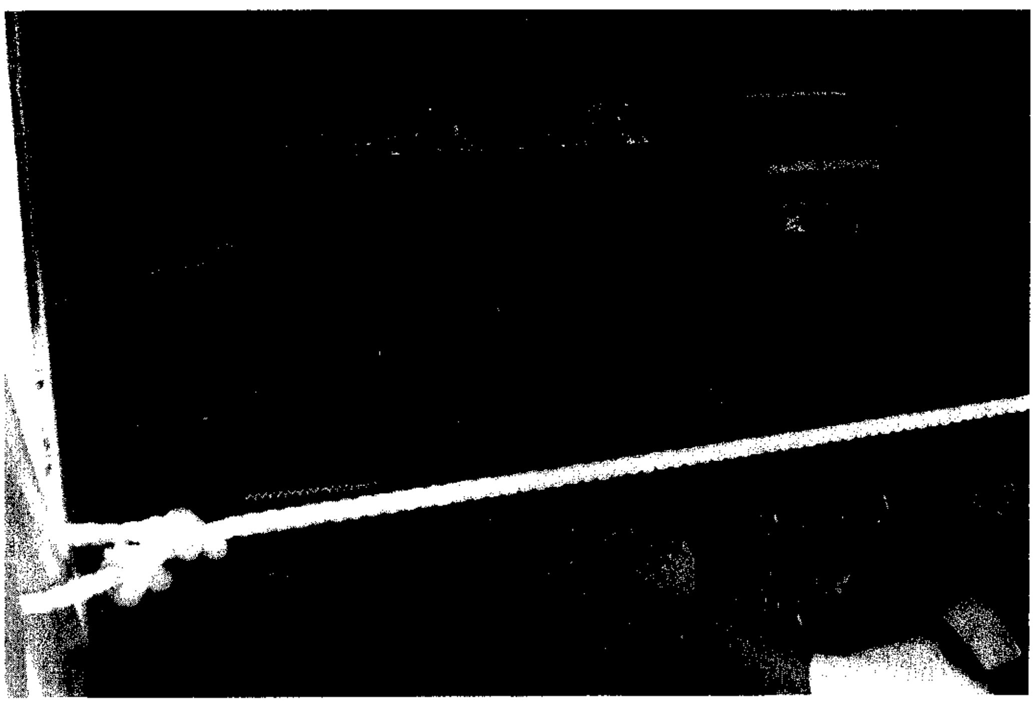

Figure 5. Photographs of sampling basket on deck (upper photo) and photo of sampling basket and grating in hopper after sampling (lower photo). Biologist in lower photo is standing on grating to attach winch to remove basket that contains current sample.

3.2 SAMPLING PROTOCOL

The initial sampling protocol developed at the start of the study assumed 100 percent containment of the slurry during sampling. Samples were to be collected over a uniform time period at the beginning and end of each "cut," defined as the period during which the dragarms are lowered and dredging is occurring. It takes one to several "cuts" to fill a hopper depending on the length of the area that is being dredged. Dredging can only occur while the vessel is moving in a forward direction. During normal dredging operations, the pumps for both dragarms are operated simultaneously, and the pump speed is maintained at approximately 2,500 rpm. On May 16, 1997, initial testing with both pumps running at 2,500 rpm resulted in material flowing over the top of the sampling basket (Figure 6, upper photo). A redesign of the sampling equipment was not feasible because of time constraints. Field tests subsequently determined that running one pump at 750 - 1,000 rpm would result in 100 percent containment of the dredge material (Figure 6, lower photo).

The sample period extended from the time the draghead was lowered to the channel floor to the time the draghead was lifted off the channel floor. During each sample collection, there was a period of time when water flowed through the dragarm before and after the actual sampling period. This was necessary to clean any debris from the dragarm prior to turning the pumps off. The general sample collection sequence began when the bridge crew turned on the dragarm pump, adjusted the pump speed, lowered the draghead to the channel floor, and then began timing the sample period. Once the sample period was over, the bridge crew would raise the dragheads while continuing to run the pump until clear water was seen running through the dragarm. The initial sample collection period was five minutes. However, this duration often resulted in too much material collecting in the basket, thereby causing the basket to overflow rendering the sample void (basket overflow could allow juvenile salmonids to escape from the collection basket). Consequently, the sample period was therefore reduced to two minutes at most locations.

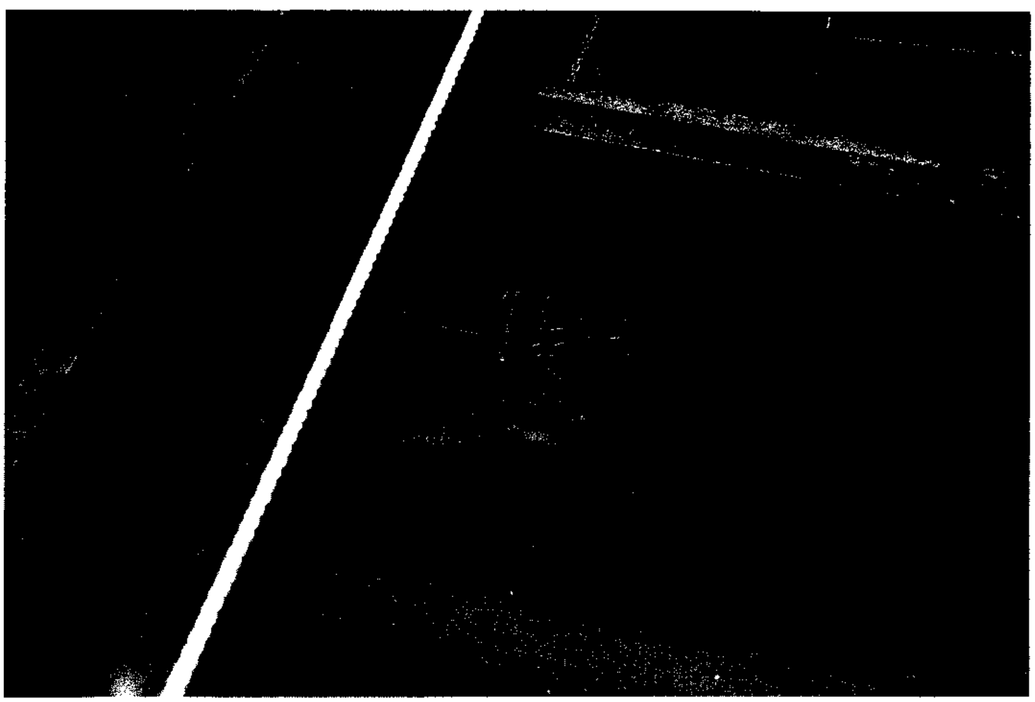

Figure 6. View looking into hopper during normal dredging with normal pump speed, while grating is in place and without sampling basket in place (upper photo). View during sampling with basket in place (lower photo).

Another modification in sample collection was needed in areas having high proportions of gravel, cobble or other large substrate materials. In these areas, if the dragheads were set on the channel floor, the sampling basket filled rapidly (less than 10 seconds in several instances) (Figure 7). Thus, it was necessary to keep the dragarm positioned slightly above the channel floor in order to collect samples.

At the end of the sampling period, the basket was removed from the hopper and the contents of the sampling basket were sorted. Organisms were separated from the debris by hand, salmonids were identified by species, counted, length measured, and frozen for further examination. Other fish and commercially important macroinvertebrates were identified (Bond 1973, Hart 1973; Jensen 1995; Miller and Lea 1972; Smith and Carlton 1975), counted, and released.

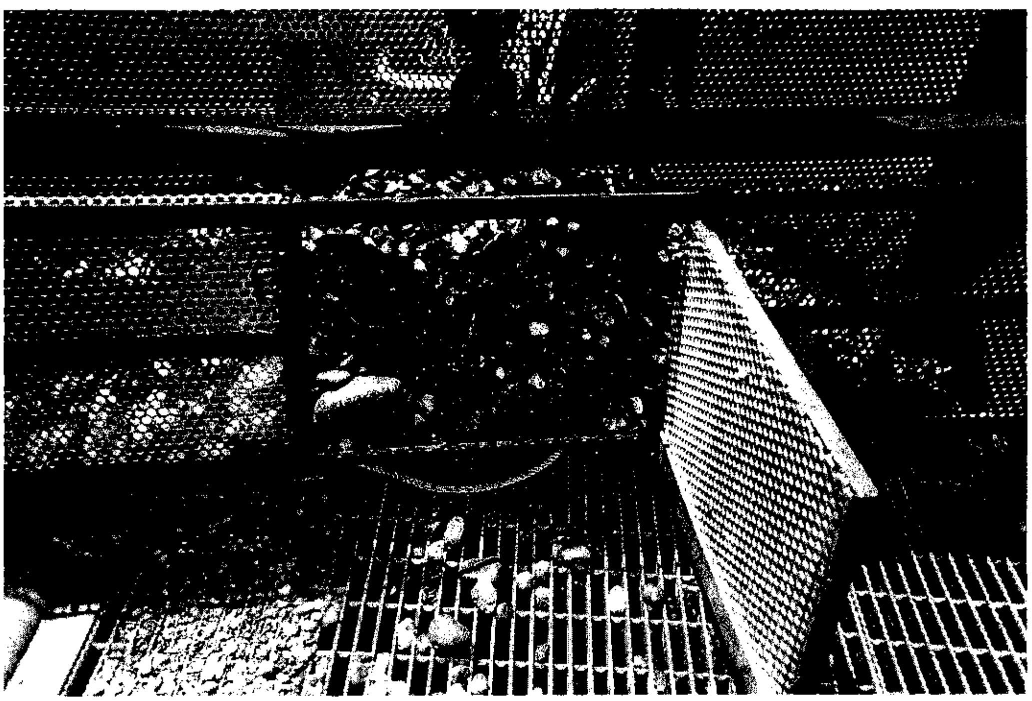

Figure 7. Example of a dredge sample comprised of coarse material too large to pass through the ¼-inch slots of the grating.

4. RESULTS

During the 1997 and 1998 surveys, 391 samples were collected from the seven sampling locations. Although numerous non-salmonid species of fish were routinely captured in the samples, including both bottom and near-bottom dwellers, only two juvenile chinook salmon (*Oncorhynchus tshawytscha*) were caught. Both of these were caught during sampling efforts in the Columbia River (Table 3). This section describes the results specific to each study location.

Table 3. Summary of sampling locations, dates, number of samples, and number of salmonids caught during the 1997-1998 surveys.

Sampling Location	Date	Number of Samples	Salmonids Entrained
Columbia River #1	May 16-19, 1997	42	2
Columbia River #2	August 20-26, 1997	98	0
Yaquina River	June 8-12, 1997	50	0
Siuslaw River	June 27-30, 1997	61	0
Umpqua River	June 30-July 2, 1997	52	0
Rogue River	June 5 and 9, 1998	23	0
Chetco River	June 6-8, and 10, 1998	65	0

4.1 COLUMBIA RIVER

Two sites were sampled in the Columbia River, the first (No. 1) was located between River Mile (RM) 70.7 and 71.9 near Longview, Washington. The second (No. 2) was between RM 106 and 114 at Tomahawk and Airport bars. These two sites were sampled from May 16 to 19, 1997 and from August 20 to 26, 1998, respectively. Fish entrainment sampling at the Columbia River No. 1 site was conducted from dusk to dawn during normal dredging operations within the river channel. Samples were initially taken for a duration of five minutes at the beginning and end of each load. On the second night of sampling, samples were collected at the beginning, middle, and end of each load. These intervals between samples were considered to be too long (up to an hour and forty minutes between some samples) and on the third night, the sampling interval was changed to every 30 minutes and the sampling duration was reduced to two minutes (see Section 3.2). Because the substrate in the lower Columbia contains substantial amounts of cobble and gravel, the dragarms were kept off the channel floor during sampling.

C29618

Table 4. Summary of fish and invertebrates entrained, by location, during 1997-1998 sampling.

Species	Columbia		Yaquina River	Siuslaw River	Umpqua River	Rogue River	Chetco River
	Site 1	Site 2					
Chinook Salmon (*Oncorhynchus tshawytscha*)	X						
Lingcod (*Ophiodon elongatus*)			X				
Pacific Sandfish (*Trichodon trichodon*)				X	X		
Sandlance (*Annodytes hexapterus*)			X	X	X		
White Sturgeon (*Acipenser transmontanus*)	X						
Flatfish (*Pleuronectiformes*)			X	X	X		X
Gunnel (*Pholidae*)							X
Perch (*Embiotocidae*)							X
Sculpin (*Cottidae*)			X	X	X		X
Smelt (*Osmeridae*)					X	X	X
Dungeness Crab (*Cancer magister*)			X	X	X		X
Hairy Rock Crab (*Cancer jordani*)			X				
Red Rock Crab (*Cancer productus*)			X				
Hermit Crab (*Anomura*)			X	X			
Green Crab (*Carcinus maenas*)							X
Kelp Crab (*Pugettia* sp.)			X				X
Shrimp (*Cragion* sp.)			X	X	X	X	X
Snails (*Gastropoda*)			X				
Isopods (*Isopoda*)			X				X
Sand Dollars (*Dendraster excentricus*)			X	X	X		
Starfish (*Asteroidea*)			X				X
Jellyfish (*Scyphozoa*)			X				
Razor Clams (*Siliqua patula*)				X	X		
Varnish Clams (*Corbicula* sp.)		X					

C29619

During the four evenings of sampling in May 1997, a total of 48 samples were collected; 6 samples were voided because the basket filled with gravel. Overall, two juvenile chinook salmon and one white sturgeon (*Acipenser transmontanus*) were entrained. The first juvenile chinook salmon was entrained at 0358 hrs during the first night of sampling (May 16). No fish were caught the second night (May 17). The white sturgeon and the second chinook were caught at 2040 hrs and 2110 hrs, respectively, during the third night of sampling (May 18). All three specimens were in good condition and vigorous when caught. The two chinook were retained and frozen for further analysis; the white sturgeon was released. It was determined that the two chinook salmon were from hatchery stock, and were believed to be the product of a hatchery release that took place within a few days of the entrainment sampling on the lower Columbia River (personal communication Kim Larson, USACE).

The No. 2 Columbia River site was sampled from August 20 to 26, 1998. The sampling was conducted at two locations: Tomahawk Bar, at approximately RM 106, and Airport Bar, at approximately RM 113 and 114. Sampling was conducted at Tomahawk Bar on August 20, 25, and 26, 1998, and at Airport Bar from August 21 to 25, 1998. Sampling sessions were conducted from 1200 hrs to 2400 hrs, and at dawn.

During initial sampling at Tomahawk Bar, it was noticed that modifications made since the previous sampling session had raised the sampling basket, allowing some of the flow to pass between the basket and the grating outfall. The sampling equipment was repaired, and sampling resumed. Because of the substrates (compacted sand and woody debris) contained at these sites, the dragheads were kept off the bottom during sampling.

During the seven days of sampling, a total of 106 samples were collected, of which eight samples were voided; no salmonids were entrained. The only biota observed in the samples were several varnish clams (*Corbicula* sp.).

4.2 YAQUINA RIVER

Fish entrainment sampling was conducted from June 8 to 12, 1997 at the mouth of the Yaquina River at Newport, Oregon, between the north and south jetties. Sampling was conducted initially at the beginning and end of each load. Because this time interval between samples was determined to be too long, the sampling was changed to two-minute samples every half hour. The substrate at the mouth of the Yaquina River was primarily composed of sand, the majority of which was fine enough to pass through the grating and sampling basket holes. Consequently, the dragarms were allowed to remain on the channel floor during sampling. Sampling was generally conducted from 1200 hrs to 2400 hrs, with several dawn samples also taken.

A total of 50 samples were collected during the sampling period; no salmonids were captured. However, a variety of other fish and invertebrates were entrained including flatfish (*Pleuronectiformes*), lingcod (*Ophiodon elongatus*), sandlance (*Annodytes hexapterus*), sculpin (*Cottidae*), Dungeness crab (*Cancer magister*) (adult and juvenile), red rock crab (*Cancer productus*) (adult and juvenile), hairy rock crab (*Cancer jordani*), kelp crab (*Pugettia* sp.), hermit crabs (*Anomura*), shrimp (*Cragion* sp.), jellyfish (*Scyphozoa*), starfish (*Asteroidea*), sand dollars (*Dendraster excentricus*), snails (*Gastropoda*), and isopods (*Isopoda*). Most of the entrained organisms appeared to be in good condition except for sandlance, many of which were injured or dead.

4.3 SIUSLAW RIVER

The mouth of the Siuslaw River near Florence, Oregon, was sampled from June 27 to 30, 1997. Sampling was conducted for two minutes every 30 minutes from 1200 hrs to 2400 hrs; a few dawn samples were also taken. The substrate at this site was composed of sand and small debris, allowing the dragarms to remain on the channel floor during sampling.

Sixty-one samples were collected from the Siuslaw River; no salmonids were entrained. A variety of other fish and invertebrates were captured including flatfish, sandlance, sculpin, Pacific sandfish (*Trichodon trichodon*), Dungeness crab (adult and juvenile), hermit crab, shrimp, razor clams (*Siliqua patula*), and sand dollars.

4.4 UMPQUA RIVER

Sampling within the Umpqua River occurred from June 30 to July 2, 1997. The sampling protocol of two-minute samples collected every 30 minutes from 1200 hrs to 2400 hrs was followed; a few dawn samples were also collected. The substrate at this site was composed of sand and small debris, allowing the dragarms to remain on the channel floor during sampling.

Fifty-three samples were collected from the Umpqua River of which one was void. Although no salmonids were captured, a variety of other fish and invertebrates were entrained including flatfish, sandlance, sculpin, smelt, Pacific sandfish, Dungeness crab (adult and juvenile), shrimp, razor clams, and sand dollars.

4.5 ROGUE RIVER

Sampling at the mouth of the Rogue River at Gold Beach, Oregon, began on June 5, 1998. The substrate was a combination of sand, gravel and cobble, which required keeping the dragheads just off the bottom. The protocol of two-minute samples collected every 30 minutes was followed. Dredging was halted for several hours at midday due to low tides, and sampling was suspended on June 6 because high winds made conditions unsafe for dredging. Sampling resumed on the morning of June 9, but was again suspended on June 10 due to rough conditions.

A total of 26 samples were taken at Gold Beach on the Rogue River, of which three were void. No salmonids were entrained; and several shrimp and one smelt (*Osmeridae*) were the only biota found in the samples.

4.6 CHETCO RIVER

The mouth of the Chetco River at Brookings, Oregon, was sampled from June 6 to 8, and on June 10, 1998. The sampling protocol of two-minute samples, every 30 minutes from 1200 hrs to 2400 hrs was followed. Because substrates at Brookings were a combination of sand, gravel, and cobble, the dragheads were kept off the bottom during sampling.

A total of 70 samples were collected at the Chetco River, of which five samples were void. No salmonids were entrained, but a variety of other fish and invertebrates were captured including flatfish, perch (*Embiotocidae*), sculpin, smelt, gunnel (*Pholidae*), Dungeness crab (adult and juvenile), cancer crab, kelp crab, green crab (*Carcinus maenas*), shrimp, starfish, and isopods.

5. DISCUSSION

During the two seasons of sampling (1997 and 1998) a total of 391 valid (i.e., not voided) samples were collected during this study. The sampling locations included two sites in the lower Columbia River and five sites along the Oregon Coast. While the periodicity tables indicate that it is likely juvenile salmon were present at most locations at the time the sampling was conducted, only two juvenile chinook salmon of hatchery origin were caught during this study. This suggests that dredging activities, as currently practiced by the Portland District USACE, are not likely to entrain juvenile salmonids, including those listed under the ESA. This is especially true given that two of three sampling protocols resulted in changes from normal dredging operations that would likely increase the probability of salmonid capture.

The first protocol was the necessity of keeping the draghead off the channel floor during sampling at locations that had coarse substrate. Holding the dragarm off the channel bottom would likely result in a higher probability of entraining organisms that reside in the water column slightly above the channel floor (e.g., salmonids) than would occur under normal dredging operations. This sampling modification could thus bias the results, leading to an overestimate of salmonid entrainment during dredging. Furthermore it should be noted that many other species of fish and organisms were caught during the sampling, suggesting that the sampling methodology was effective.

The second sampling protocol that differed from normal dredging operations that may increase the probability of salmonid captures pertained to the duration of sample collection. In general, this was relatively short (a few minutes) compared to normal operations. As a result, the proportion of time in which the draghead was in the water column (during deployment and sample recovery) versus on the channel bottom was higher during these surveys than would occur under normal dredging operations.

The third protocol was the operational requirement to decrease the pump speed during sampling. This resulted in a smaller impact area around the draghead than normally occurs during dredging. Fewer individual organisms were likely entrained per unit time during sampling because of the decreased pump speed. However, the species composition of the sample was probably unaffected by this modification.

Overall, the capture of only two juvenile salmonids during the entire sample period can likely be explained by one or more of the following:

a) juvenile salmonids were present, but dredging operations, as currently practiced, pose little risk of entrainment of salmonids;

b) juvenile salmonids were not present in the locations in which dredging occurred because of non-utilization of habitats specific to dredging areas (i.e., juvenile salmonids present within the channel, but not within the dredged areas); or

c) juvenile salmonids were not present in the locations in which dredging occurred because of differences in timing of downstream migrations (i.e., juvenile salmonids were not present).

Based on the periodicity information, we believe that juvenile salmonids should have been present in all of the sites sampled during this study and therefore, consider the last explanation unlikely. Given that the dredge sampling encompassed relatively large areas within each site, it also seems unlikely that juvenile salmonids would have selectively avoided all of the specific areas in which dredging occurred, rendering explanation (b) implausible. This leaves explanation (a) which we consider the most likely reason very few salmonids were recovered during the dredge sampling.

A possible improvement for future entrainment studies would be to redesign the sampling equipment to allow the dragarm pumps to run at speeds closer to that of normal dredging operations for longer sampling periods. However, the sampling procedure will always be constrained by the presence of coarse substrates and large debris that require the dragarms to be kept off the channel bottom during sampling, resulting in higher estimated entrainment numbers then would be expected under normal dredging operations.

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